CARVE: L2 Atmospheric Gas Concentrations, Airborne Flasks, Alaska, 2012-2015

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Documentation Revision Date: 2016-11-14

Data Set Version: V1

Summary

This data set provides atmospheric carbon dioxide (CO2), methane (CH4), carbon monoxide (CO), molecular hydrogen (H2), nitrous oxide (N2O), sulfur hexafluoride (SF6), and other trace gas mole fractions (i.e. "concentrations") from airborne campaigns over the Alaskan and Canadian Arctic for the Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE). The CARVE flight campaigns took place from 2012 to 2015 between the months of March and November to enable investigation of both seasonal and inter-annual variability in atmospheric gas abundances. The data were derived from laboratory measurements of whole air samples collected by a Programmable Flask Package (PFP) onboard the CARVE aircraft. Air samples were collected at strategic intervals to coincide with the overflight of a ground site of interest, or when interesting geophysical conditions were encountered. While most of these samples were collected near the surface in the planetary boundary layer (PBL), on almost every flight samples were also collected in the free troposphere. A minimum of 12 flask samples were collected per flight. Whole air samples collected in the PFPs were analyzed on automated systems at the NOAA Earth System Research Laboratory (ESRL) Global Monitoring Division in Boulder, CO, which also analyzes samples from the NOAA/ESRL Global Greenhouse Gas Reference Network. The measurements included in this data set are crucial for understanding changes in Arctic carbon cycling and the potential threats posed by thawing of Arctic permafrost.

These measurements are one part of an innovative multi-instrument remote sensing payload flown for the CARVE investigation.

There are 4 data files in netCDF (*.nc) format, one for each year of CARVE campaign flights, with this data set.

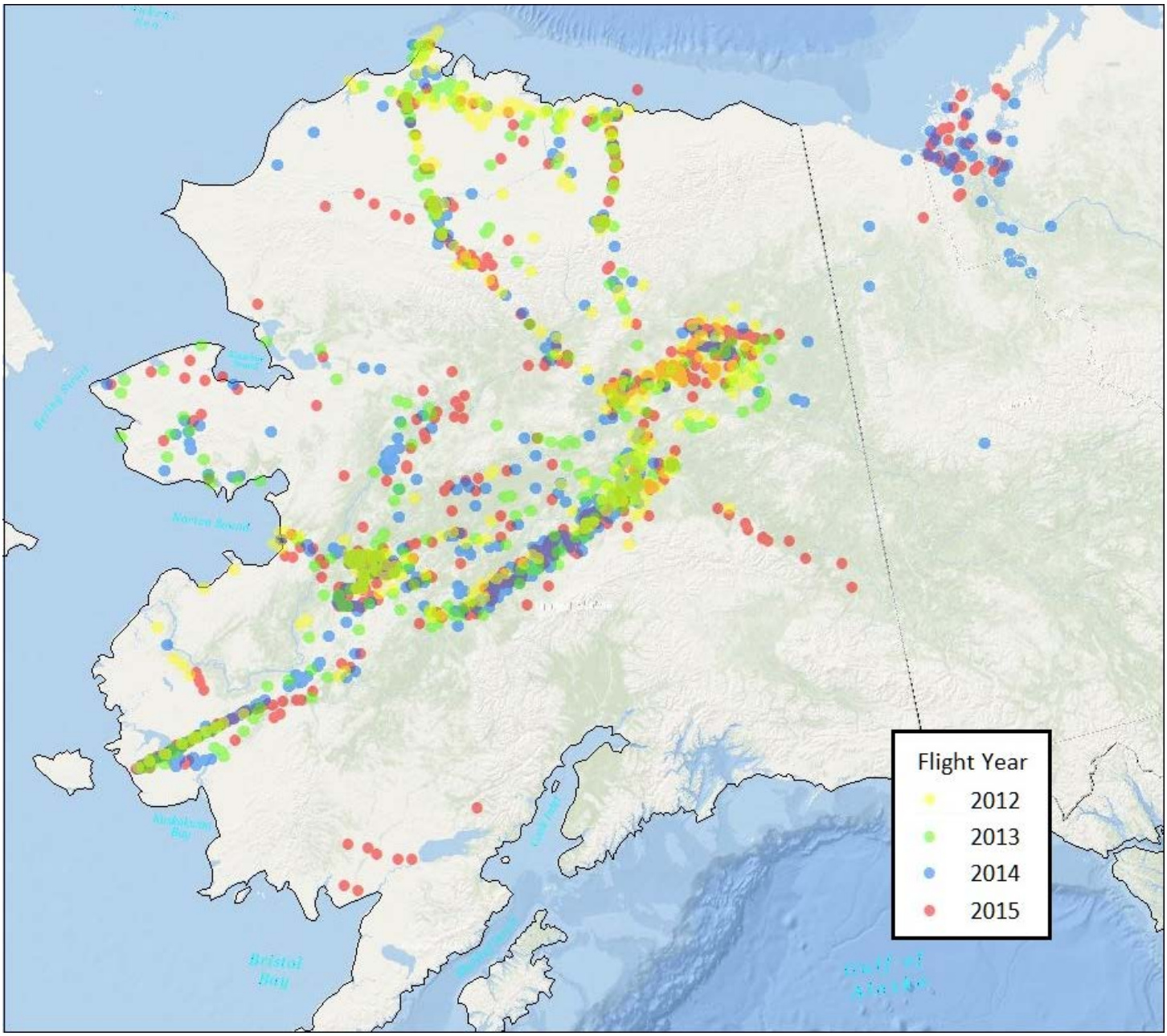

Figure 1: Locations of CARVE flask air samples from flights between 2012-2015

Citation

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1. Data Set Overview

Project: Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE)

The Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) is a NASA Earth Ventures (EV-1) investigation designed to quantify correlations between atmospheric and surface state variables for Alaskan terrestrial ecosystems through intensive seasonal aircraft campaigns, ground-based observations, and

analysis sustained over a 5-year mission. CARVE collected detailed measurements of greenhouse gases on local to regional scales in the Alaskan Arctic and demonstrated new remote sensing and improved modeling capabilities to quantify Arctic carbon fluxes and carbon cycle-climate processes. CARVE science fills a critical gap in Earth science knowledge and satisfies high priority objectives across NASA's Carbon Cycle and Ecosystems, Atmospheric Composition, and Climate Variability & Change focus areas as well as the Air Quality and Ecosystems elements of the Applied Sciences program. CARVE data also complements and enhances the science return from current NASA and non-NASA sensors.

Related Data:

A full list of CARVE data products is available at: https://carve.ornl.gov/dataproducts.html

2. Data Characteristics

Spatial Coverage: CARVE flights over the Alaskan and Canadian Arctic

Spatial Resolution: Point measurements

Temporal Coverage: 20110329 - 20151112

Temporal Resolution: The instruments were deployed on periodic flights during the growing season (approx. March – November). Measurements were initiated by the aircraft pilot at scheduled times coinciding with overflight of an area of interest, or when interesting geophysical conditions were encountered. A minimum of 12 flask samples were collected per flight.

Study Area (coordinates in decimal degrees)

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude
Alaska and Canadian Arctic	-167.4810	-104.3540	71.4985	35.2004

Data File Information

All data are stored in NetCDF (*.nc) version 4 file format. Each file provides measurements of dry mole fractions of atmospheric CO_2, CH_4, CO, H_2, N_2O, and SF_6 acquired over one year of CARVE flights.

Table 1: CARVE file naming convention. Example file name: carve_Flask_L2_b23_20121001_20160807204049.nc

Name element	Example value	Units
Project name	*carve*	
Instrument	*Flask*	
Processing level	*L2*	
Build ID	*b23*	
Flight date start	*20121001*	*yyyymmdd*
Processing date and time	*20160807204049*	*yyyymmddhhmmss*

Data variables

Each file contains 14 geolocation and ancillary variables and 69 science measurement variables described in Table 2.

Table 2. Data variables in each netCDF file. Fill value or missing data were set to -999.9 for all variables.

Variable name	Description	Units

Geolocation and ancillary measurements		
center_lat	latitude	decimal degrees North
center_lat_standard_error	latitude standard error	decimal degrees North
center_lon	longitude	decimal degrees East
center_lon_standard_error	longitude standard error	decimal degrees East
height	height of aircraft above ground	meters
height_standard_error	height standard error	meters
geolocation_qc	geolocation status flag	0 = Success, 1 = Error
time	time of sample collection	seconds since 1980-1-6 0:0:0
elevation	surface elevation	meters
event_number	NOAA database event number	
intake_height	sample intake height	meters
flask_id	sample container ID	
sample_method	sample collection method	
site_code	sample site code	
Science measurements		
benz	benzene (C_6H_6)	parts per trillion (ppt) *
brfm	bromoform ($CHBr_3$)	ppt
c2f6	hexafluoroethane (CF_3CF_3)	ppt
c2h2	ethyne (acetylene; C_2H_2)	ppt
c2h4	ethene (ethylene; C_2H_4)	ppt
c2h6	ethane (C_2H_6)	ppt

c3h6	propene (propylene; C_3H_6)	ppt
c3h8	propane (C_3H_8)	ppt
ccl4	carbon tetrachloride (tetrachloromethane; CCl_4)	ppt
cf4	carbon tetraflouride (tetrafluoromethane; CF_4)	ppt
ch2brcl	bromochloromethane (CH_2BrCl)	ppt
ch3i	methyl iodide (CH_3I)	ppt
ch4	methane (CH_4)	parts per billion (ppb) *
chlf	chloroform ($CHCl_3$)	ppt
co	carbon monoxide (CO)	ppb
co2	carbon dioxide (CO_2)	parts per million (ppm) *
co2c13	$d^{13}C$ of CO_2	ppm
co2c14	$d^{14}C$ of CO_2	ppm
co2o18	$d^{18}O$ of CO_2	ppm
cs2	carbon disulfide (CS_2)	ppt
dibr	dibromomethane (CH_2Br_2)	ppt
dicl	dichloromethane (CH_2Cl_2)	ppt
f112	CFC-112 (CCl_3CClF_2)	ppt
f113	CFC-113 (CCl_2FCClF_2)	ppt
f114	CFC-114 and CFC-114a (ClF_2CCF_2Cl)	ppt
f115	CFC-115 ($CClF_2CF_3$)	ppt

f11a	CFC-11 (ion 101; CCl_3F)	ppt
f11b	CFC-11 (ion 103; CCl_3F)	ppt
f124	HCFC-124 ($CHClFCF_3$)	ppt
f125	HFC-125 (CHF_2CF_3)	ppt
f13	CFC-13 ($CClF_3$)	ppt
f134	HFC-134 (CHF_2CHF_2)	ppt
f134a	HFC-134a (CH_2FCF_3)	ppt
f141b	HCFC-141b (CH_3CCl_2F)	ppt
f142b	HCFC-142b (CH_3CF_2Cl)	ppt
f143a	HFC-143a (CH_3CF_3)	ppt
f152a	HFC-152a (CH_3CHF_2)	ppt
f160	chloroethane (CH_3CH_2Cl)	ppt
f227e	HFC-227ea (CF_3CHFCF_3)	ppt
f23	HFC-23 (CHF_3)	ppt
f236fa	HFC-236fa ($CF_3CH_2CF_3$)	ppt
f32	HFC-32 (CH_2F_2)	ppt
f365m	HFC-365mfc ($CH_3CF_2CH_2CF_3$)	ppt
fc12	CFC-12 (CCl_2F_2)	ppt
h1211	bromochlorodifluoromethane (halon 1211; $CBrClF_2$)	ppt
h1301	bromotrifluoromethane (halon 1301; CF_3Br)	ppt
h2	hydrogen (H_2)	ppb
	dibromotetrafluoroethane (halon 2402;	

h2402	$CBrF_2CBrF_2$)	ppt
hf133a	HCFC-133a (CH_2ClCF_3)	ppt
hf21	HCFC-21 ($CHCl_2F$)	ppt
hf22	HCFC-22 (CHF_2Cl)	ppt
ic4h10	i-butane (i-C_4H_{10})	ppt
ic5h12	i-pentane (i-C_5H_{12})	ppt
mcfa	methyl chloroform (ion 97; CH_3CCl_3)	ppt
mebr	methyl bromide (CH_3Br)	ppt
mecl	methyl chloride (CH_3Cl)	ppt
n2o	nitrous oxide (N_2O)	ppb
nc4h10	n-butane (n-C_4H_{10})	ppt
nc5h12	n-pentane (n-C_5H_{12})	ppt
nc6h14	n-hexane (n-C_6H_{14})	ppt
nf3	nitrogen trifluoride (NF_3)	ppt
ocs	carbonyl sulfide (COS)	ppt
p218	perfluoropropane (C_3F_8)	ppt
pce	tetrachloroethylene (C_2Cl_4)	ppt
sf6_ccgg	sulfur hexafluoride (SF_6)	ppt
sf6_hats	sulfur hexafluoride (SF_6)	ppt
so2f2	sulfuryl fluoride (SO_2F_2)	ppt
tce	trichloroethylene (C_2HCl_3)	ppt
tol	toluene (C_7H_8)	ppt

* parts per million – ppm – micromol of gas per mol of dry air – 10^{-6}

  parts per billion – ppb – nanomol of gas per mol of dry air – 10^{-9}

  parts per trillion – ppt – picmol of gas per mol of dry air – 10^{-12}

The netcdf files also include a QC flag for each analyte. For example, the benzene ratio QC flag is “benz_ratio_status”. The flag values are the same for all analytes and are provided in Table 3.

Table 3. QC flag value descriptions

QC Flag	Flag Meaning	Description
1	Valid	
2	Preliminary	Sample measurement is preliminary and has not yet been carefully examined by the PI
3	Deselected	Sample measurement is likely valid but does not meet selection criteria determined by the goals of the CARVE investigation
4	Rejected	Obvious problems during collection or analysis

Calibration:

All measurements are reported as dry air mole fractions on their respective World Meteorological Organization (WMO) standard scales:

- NOAA 2004 CO standard scale (see Novelli et al., 1991)
- NOAA 2007 CO2 standard scale (see Zhao and Tans, 2006)
- NOAA 2004 CH4 standard scale (see Dlugokencky et al., 2005)
- NOAA 2004 CMDL H2 standard scale (Novelli et al., 1999)
- NOAA 2006A N2O standard scale (Hall et al., 2007)
- NOAA 2006 SF6 standard scale (Hall et al., 2011)

3. Application and Derivation

These data files contain dry mole fractions of CO, CO2, CH4, H2, N2O, and SF6 measured from whole air samples collected during CARVE flights between March and November of 2012 to 2015. These data complement high-frequency gas concentration observations from the Fourier transform spectrometer and cavity ring-down spectroscopy instruments aboard CARVE flights.

The CARVE project was designed to collect detailed measurements of important greenhouse gases on local to regional scales in the Alaskan arctic and demonstrate new remote sensing and improved modeling capabilities to quantify Arctic carbon fluxes and carbon cycle-climate processes. The CARVE data provide insights into Arctic carbon cycling that may be useful in numerous applications.

4. Quality Assessment

Table 4. Repeatability of gas detection was determined as 1 standard deviation of ~20 aliquots of natural air measured from a standard cylinder.

Gas	Average Repeatability
CO	UV Resonance fluorescence: +/- 0.4 ppb (Gerbig et al., 1999)
CO2	+/- 0.03 ppm (Conway et al., 1994)
CH4	+/- 1.2 ppb (Dlugokencky et al., 1994)
H2	+/- 0.4 ppb (Novelli et al., 1999)
N2O	+/- 0.26 ppb (Dlugokencky et al., 2009)

SF6	+/- 0.03 ppt (Dlugokencky et al., 2009)

5. Data Acquisition, Materials, and Methods

CARVE Flights

These data represent one part of the data collected by the Carbon in Arctic Reservoirs Vulnerability Experiment (Miller & Dinardo, 2012). A C-23 Sherpa aircraft made frequent flights out of Fairbanks, Alaska between March and November over multiple years, observing the spring thaw, summer draw-down, and fall refreeze of the Arctic growing season. Flights concentrate observations on three study domains: the North Slope, the interior, and the Yukon River valley. North Slope flights cover regions of tundra and continuous permafrost and were anchored by flux towers in Barrow, Atqasuk, and Ivotuk. Flights to Prudhoe Bay characterize the CO2 and CH4 emissions from oil and natural gas processing plants. Flights over interior Alaska sample discontinuous permafrost, boreal forests, and wetlands. A complete list of CARVE flights can be found at: https://carve.ornl.gov/flights.html. Flight paths and atmospheric gas concentrations for CARVE surveys can be visualized through the CARVE Flight Data Visualization Tool (http://carve.ornl.gov/visualize) and are illustrated in Figure 2.

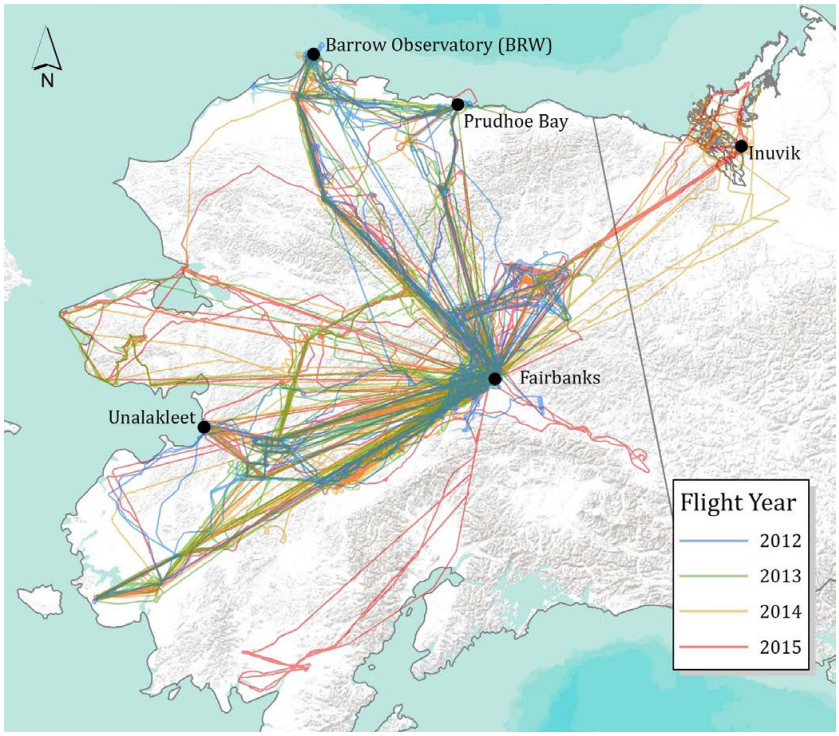

Figure 2. CARVE flights during 2012-2015 delivered measurements over continuous and discontinuous permafrost regimes.

The CARVE aircraft carried a remote sensing and atmospheric sampling payload consisting of the following instruments: a Fourier transform spectrometer (FTS), and an in situ gas analyzer suite (ISGA) with a gas analyzer and PFP sampling system (see https://carve.ornl.gov/documentation.html). All instruments were controlled by a master computer system (Data Acquisition and Distribution System, DADS). Data were logged and UTC time stamped at 1 second intervals. DADS also recorded GPS data (Lat, Lon, elevation), aircraft pitch, roll, and yaw, as well as basic meteorological data from onboard instruments.

Flask air sampling system

This data set includes measurements from discrete air samples captured by the flask sampling system on board the aircraft. The two air-sampling devices, the Programmable Flask Package (PFP) and Programmable Compressor Package (PCP) systems, are used routinely on aircraft as part of the NOAA/ESRL Global Monitoring Division's Carbon Cycle and Greenhouse Gases network (Sweeney et al., 2013).

Figure 3. Flask sampling system for aircraft measurements. Left: Programmable Flash Package (PFP) containing 12 flasks. Right: Programmable Compressor Package (PCP) containing pumps for pressurizing the flasks. (Image courtesy: http://www.esrl.noaa.gov/gmd/ccgg/aircraft/sampling.html)

A typical sampling routine uses one PCP and one or more PFP(s) that are pre-programmed with a flight-specific sampling plan of target altitudes for each sample. Sampling is timed to coincide with the overflight of a ground site of interest, or when interesting geophysical conditions are encountered. A map of flask sample locations is depicted in Figure 1. The PCP is connected to an LED display that communicates target sampling altitudes to the pilot. The pilot maintains the aircraft at a consistent altitude for the duration of each sample collection, typically under 40 seconds. For each sample, the inlet line and compression manifold are flushed with about 5 liters of ambient air. Valves on both ends of the current flask are then opened and the flask is flushed with about 10 more liters of ambient air to displace the dry, low CO2 fill gas with which the flasks are shipped. The sample flush air is measured by a mass flow meter to ensure that a sufficient volume passes through the manifold and flask before the downstream valve is closed and pressurization begins. Sample flush volumes and fill pressures during sampling are recorded by the data logger, along with ambient temperature, pressure, and relative humidity. GPS position and time stamp are also recorded with each sample.

Gas detection

- Quantities of CO2 in flask air samples were detected using a non-dispersive infrared analyzer and reported in parts per million (ppm). Because detector response is non-linear in the range of atmospheric levels, ambient samples are bracketed during analysis by a set of reference standards used to calibrate detector response.
- CH4 was isolated from constituent gases through gas chromatography and quantified with flame ionization detection. Measurements are reported in parts per billion (ppb).
- CO was isolated from constituent gases with gas chromatography and detected by resonance fluorescence at ~150 nm, or by reaction with HgO to produce mercury and detection through Hg resonance absorption, and reported in ppb.
- H2 was isolated using gas chromatography, reacted with HgO, and detected through Hg resonance absorption. H2 quantities are reported in ppb.
- The N2O and SF6 sample components were isolated using gas chromatography and quantified with electron capture detection. N2O and SF6 are reported in ppb and parts per trillion (ppt), respectively.

6. Data Access

These data are available through the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

CARVE: L2 Atmospheric Gas Concentrations, Airborne Flasks, Alaska, 2012-2015

Contact for Data Center Access Information:

- E-mail: uso@daac.ornl.gov
- Telephone: +1 (865) 241-3952

7. References

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